Proposal for Cleaner Transit Buses

The ARB is developing a proposal for low-emission transit buses that would have a long-term requirement for zero or near-zero bus emissions in California. In the short-term, this proposal would provide incentives for transit agencies that implement low-emission technology immediately.

ARB has taken action statewide to assure that all mobile sources of air pollution bear some responsibility for improving air quality. The staff recognizes that the transit operators' primary responsibility is to efficiently provide convenient transportation. Meeting the transportation needs of commuters, students, transit-dependent riders and reducing traffic congestion are high priorities in our society. However, current diesel buses usually emit more pollutants than if the bus riders drove alone in their cars.

Cleaner, alternative-fuel technology is currently an available method of achieving significant emissions benefits for both transit and school buses. Staff originally considered a straightforward proposal that would immediately require all new bus purchases to be low-emission based on the ability of cleaner alternative-fuel technology to meet the lower emissions standards. ARB staff's current proposal is designed to provide the same emissions benefit, give the transit districts greater flexibility in making their operations part of the clean air solution, and still encourage cleaner buses immediately.

What are some impacts of air pollution?

California has a serious, statewide ozone air pollution problem, including the worst air quality in the United States in the South Coast Air Basin (Los Angeles, San Bernardino, Riverside, and Orange Counties). Air pollution directly impacts public health, ranging from eye irritation, sore throats and coughing to lung damage, cancer and premature death. Healthy children and adults who play or exercise vigorously are also at risk. Federal requirements dictate that the South Coast Air Basin meet national ambient air quality standards for ozone by 2010. Other regions within California have even earlier attainment requirements.

The particulate emissions from diesel-fueled engines have been identified as a toxic air contaminant, one that causes cancer. In fact, preliminary estimates indicate that the particulate emissions from diesel-fueled engines are by far the most significant mobile source toxic risk faced by citizens of California. The ARB has adopted the goal of reducing exposure to diesel particulate emissions in order to protect the public health. Additional information on the specific toxic risk from particulate emissions at such locations as bus depots and bus stops is currently being determined.

What bus pollutants are we most concerned with?

Current diesel buses have relatively high emissions of oxides of nitrogen (NOx) and particulates. NOx is critical because it is one of the two major components that create ozone (or smog). Particulates, as discussed above, are a significant toxic air contaminant. Diesel engines have relatively low emissions of carbon monoxide (CO), carbon dioxide ($CO_{2)}$, and non-methane hydrocarbons (NMHC). CO emissions create hot spots that affect public health, although nearly all areas of California are in attainment for CO. CO_2 is a greenhouse gas that contributes to global warming. Emissions of NMHC are critical because in combination with NOx emissions they create ozone.

A natural gas bus will have significantly lower NOx and particulate matter (PM) emissions than a comparable diesel engine. A natural gas bus is also likely to have higher CO and CO_2 emissions and slightly higher NMHC emissions. However, the increase in these emissions is small compared to the decrease in NOx emissions.

Who would be affected by this proposal?
This proposal is composed of two parts: a fleet rule applicable to transit districts and a regulation setting lower emission standards for urban buses. As proposed, the fleet rule would affect new purchases and leases of full-size buses. It would consider fleet size and normal fleet turnover rates. The proposed new urban bus standards would be implemented in phases and applicable to engine manufacturers.

Ideally, ARB staff would like all 8400 full-size transit buses, and all 23,000 school buses in California to be lower-emission immediately. However, that isn't practical. Long-term, it is generally more effective for requirements to apply to new purchases and not require retrofitting or repowering of existing buses. Also, most of the efforts by manufacturers has gone into demonstrating low-emission technology on "traditional" buses, e.g., 30 to 40 foot transit and school buses. Technology for specialized buses such as articulated buses may require additional time. These buses are currently low in sales and are not likely to be included in this proposal as long as their sales remain low.

Aren't buses just a small portion of the total air pollution problem?
Yes and no. Urban buses do not make up a significant percentage of pollutant emissions; however, all emission sources are important. The ARB and local air districts have reduced emissions from nearly all sources, including very small ones, in order to make air quality progress over the last 20 years.

Several factors make bus fleets ideally suited for improved controls. Many of these buses operate in the most heavily congested urban areas where air quality is often critical and direct exposure to toxic diesel particulates occurs. This makes the toxic particulate emissions an even greater public health concern. Diesel buses operating on city streets cause direct exposure to this toxic air contaminant to children, passengers, and others in close proximity to the buses. They are centrally fueled, allowing for a cleaner alternative fuel to be utilized efficiently. As well, transit bus fleets do not have to rely entirely on local funding. The federal government heavily subsidizes the purchase of transit buses. Also, there are often air quality funds available to offset most of the differential bus costs and some infrastructure costs.

Are lower emission benefits feasible?
Definitely. In fact, about 30 percent of California transit operators have some low-emission alternative-fuel buses, in use or on order. In most cases, their engines emit one-half the NOx and PM of comparable diesel engines. So immediate air quality benefits are possible. All diesel engines are currently certified to the dirtiest emission levels allowable; none are certified to ARB's low optional NOx standards. Therefore, there is no such thing as a "clean diesel" bus engine today.

What about future emission standards – won't diesel engines be getting cleaner?
Yes. New emission standards will require lower-emission engines. In late 2002, NOx emission requirements for most heavy-duty engines will be reduced by approximately 50 percent (2.5 g/bhp-hr NOx + NMHC), to the current NOx emission levels of natural gas engines. PM emission standards, however, will stay the same, and we expect PM emissions from natural gas buses to continue to be less than that from diesel buses. As diesel engines get cleaner, so can natural gas engines. To meet future standards, it is expected manufacturers will utilize more sophisticated fuel management and increased exhaust gas recirculation. Incorporation of these technologies into natural gas engines will also lower their emissions significantly from the current levels, continuing to make them lower emitting than the best available diesel technology.

What do we mean when we talk about alternative fuels?
Alternative fuels include compressed and liquefied natural gas, propane, methanol, electricity, and fuel cells. The most common type of low-emission alternative-fuel engine available uses natural gas. Natural gas is usually stored on-board the bus as compressed natural gas (CNG) or liquefied natural gas (LNG). Currently California transit operators have many CNG buses, a few electric buses, and LNG buses are on order by several operators. As well, CNG/electric hybrid buses are becoming available. A more detailed discussion of current and future transit bus technology (both diesel and cleaner alternative fuels) is contained in Appendix I.

What are the costs associated with low-emission natural gas buses?
Cost is a multi-faceted issue, and includes both capital and operating costs. Capital costs to the transit operator vary depending on the level of subsidized funding that is available to cover the higher costs of the low-emission buses and new or modified refueling and maintenance facilities. In general, air quality funds have been able to pay most or all of the differential cost of the buses. However, operators have generally borne a larger responsibility for the cost of the refueling and maintenance facilities.

Operating costs (including fuel, compression or liquefaction, bus and facility maintenance, and other costs) are generally not subsidized by non-transportation agencies. Differential fuel costs per mile of natural gas fleets vary depending on the current diesel fuel prices, which tend to fluctuate more than natural gas prices. (Current diesel fuel retail price averages about $1.40 per gallon and CNG about $1.20 per diesel gallon equivalent, including compression costs.) Natural gas technology is relatively new; therefore, insufficient historical data is available on maintenance costs. Different transit agencies report significantly different operating costs. In general, however, it can be expected that overall future operating costs for natural gas and diesel will be approximately equivalent. A more detailed description of the costs associated with cleaner alternative fuels is contained in Appendix II.

What other concerns are associated with low-emission alternative-fuel buses?

Additional issues discussed often include reliability, driving range, and safety. Much of the reliability issue reflects the learning curve that engine manufacturers and bus operators have experienced as they implement the relatively new natural gas bus technology. The reliability and the learning curve are tightly tied to the costs of the technology and are also discussed more extensively in Appendix II. Relatively new technologies, such as natural gas bus engines, take time to become efficient and reliable; new programs take special efforts to implement. Some transit operators and school districts report few reliability issues; others report numerous problems. ARB staff knows of no reason to conclude that natural gas engines will be any less reliable than diesel engines in the long term. However, we have noticed common factors among those successfully incorporating these engines today. Management support and involvement, training for mechanics and drivers, and qualified and experienced engineering support seem to be crucial in achieving successful operations.

The driving range of CNG buses is typically less than comparable diesel buses. This is more of an issue for transit bus operators with long runs than for school bus operators. First, operators can take steps to insure that the CNG tanks are completely full after refueling. If that doesn't give adequate range, several options are available. Some operators can schedule mid-day fueling or bus substitutions en-route, although they must consider the impact on lost revenue time and scheduling difficulties. LNG buses are also available which have greater ranges, although they may have higher fuel costs.

Safety of any new technology is always a serious issue. CNG tanks are under high pressure. A rupture of such a tank can cause severe damage. One such rupture occurred several years ago at the Los Angeles County Metropolitan Transit Authority (LACMTA). However, operators with natural gas buses have instituted rigorous inspection procedures and other safeguards. Since CNG is more volatile that diesel, modifications to existing maintenance facilities are generally necessary. These usually consist of a methane detection system, an improved ventilation system, new lighting, employee training, and containment procedures.

What has the ARB done to investigate all of these issues?
The ARB staff has visited transit operations at LACMTA, Sacramento Regional Transit District, Cleveland Regional Transit Authority, New York City Transit, Pierce Transit in Tacoma, Washington, and Dallas Area Rapid Transit and Houston Metropolitan Transit Authority in Texas. Staff has had discussions with many more transit agencies and additional site visits are planned. Staff has also questioned engine and bus manufacturers, natural gas providers, and many others.

Why wouldn't all operators move to cleaner, alternative fuels?
Just like private businesses, some transit operators welcome new technology, while others prefer a traditional approach. Governing boards of some transit agencies adopt air quality improvement as one of their goals; others do not. In some cases, operators relying solely on diesel are biased based on outdated information or misconceptions. Often, a bad experience many years ago with a new technology can remain with a transit agency and make them apprehensive about trying new technologies. Some do not know about the significant funding that could be available to offset increased costs.

A few transit agencies are well informed on the issues and are making deliberate decisions to stay with higher-polluting diesel engines for now. These transit agencies have argued that future technology is very promising, will provide even greater emission benefits, and the investment in natural gas infrastructure is not warranted. ARB is also excited about the future technologies. However, seldom have air quality benefits been achieved with a "wait and see" approach. In addition, many of the future technologies will work as well or better with natural gas than they will with diesel. So ARB believes an investment in natural gas infrastructure will continue to pay dividends. Nonetheless, the ARB staff has structured its current proposal in such a way that will allow significant flexibility for these transit agencies while maintaining the emissions benefits of the program.

What are the longer-term technical possibilities?
Longer-term possibilities include low-sulfur diesel fuel, NOx exhaust aftertreatment, hybrid electric vehicles, and fuel cell vehicles. In general, each of these technologies shows great promise for reliable, cost-effective emission reductions. A system that uses low-sulfur fuel and an advanced NOx exhaust aftertreatment, in conjunction with an optimized hybrid electric system, has the potential to achieve near-zero emissions. Fuel cell propulsion systems, although slightly longer term, show incredible promise for public transit with zero or near-zero emissions.

What type of proposal is the ARB considering?
The staff's proposal combines two main components: a fleet rule and more stringent urban bus engine standards. The fleet rule is designed to achieve early emission reductions. The engine standards are designed for long-term ultra-low and near-zero emission benefits.

Why is ARB considering a fleet rule?
A fleet rule is a departure from typical ARB rulemaking. ARB staff is proposing this type of rule to provide flexibility and incentives to transit bus operators. In determining what fleets are subject to the rule, ARB staff can consider air quality attainment status, fleet size, cost-effectiveness, and available funding. By providing incentives related to phasing-in of requirements, the proposal can reward operators already committed to low-emission fleets and encourage other operators to make that commitment. Small fleets, where it may not be cost-effective to make a substantial investment in new natural gas refueling capabilities and facility modifications, can be exempted from buying low-emission buses for a longer period of time.

What are the specifics of the fleet rule?
To provide flexibility to transit operators, ARB staff is developing a proposal with two different options for compliance with the fleet rule. The options are a “conventional/advanced technology” option and an “incentive” option.

The “conventional/advanced technology” option is for those operators that in the near-term continue to purchase or lease buses that only meet the current standards. Some transit agencies have stated that they would forego investment in cleaner alternative-fuel engines now, and instead invest in advanced technologies such as hybrid and fuel cell buses. Those agencies that follow the “conventional/advanced technology” path would bear the responsibility and potentially greater expense of introducing that zero or near-zero technology into fleets first. For these operators, new buses delivered after January 1, 2005 must meet NOx and PM standards of 0.5 g/bhp-hr and 0.01 g/bhp-hr, respectively. This represents a 75% NOx reduction and an 80% PM reduction from the 2002 requirements. See Table 1 below and Figures 1 and 2 attached to the end of this document.

The “incentive” path is for transit agencies that have already committed to cleaner alternative-fuel engines, or transit agencies that move to cleaner-than-required engines very soon after approval of a fleet rule by our Board. This option would create immediate emission reductions. Operators that have purchased buses that meet the lower emission levels (2.5 g/bhp-hr NOx and 0.03 g/bhp-hr PM) would then be eligible to delay buying buses with engines meeting the 0.5 g/bhp-hr NOx and 0.01 g/bhp-hr PM standards until 2007. To qualify for the “incentive” path, staff is considering a requirement, based on a 12-year bus life, that at least one-fourth of an operator’s fleet (including ordered buses) meets the NOx and PM lower emission levels as of January 1, 2003. The ARB is also considering an additional requirement that at least 75 percent of the buses ordered between the adoption of the fleet rule and January 1, 2003 meet the lower emission levels. See Table 1 below and Figures 1 and 2 attached to the end of this document.

TABLE 1 -- PROPOSED EMISSION LEVELS FOR TRANSIT BUSES

Year	"Conventional" Path		"Incentive" Path	
	NOx (g/bhp-hr)	PM (g/bhp-hr)	NOx (g/bhp-hr)	PM (g/bhp-hr)
2000	4.0	0.05	2.0	0.03
2003	2.0	0.05		
2005	0.5	0.01	2.0	0.01
2007			0.5	0.01
2008	0.1	0.0	0.5	0.0
2012			0.1	0.0

Whether a transit operator follows the "conventional/advanced technology" or the "incentive" path is voluntary. However, those that follow the "conventional/advanced technology" path are locked onto that path after January 1, 2003 and cannot switch to the "incentive" path after that time. It is expected many fleet operators would have to choose in the first year which path to take in order to accrue a sufficient percentage of buses meeting the lower emission levels.

Overall, the average NOx emissions through 2012 from the "conventional/advanced technology" and "incentive" compliance paths would be virtually equal. For PM there would still be a significant benefit with the "incentive" path.

What about "small" fleets?

The ARB staff believes most transit agencies will comply with the "incentive" path through the use of natural gas buses (although other options are available as long as the engines meet the proposed standards). Therefore, after analyzing natural gas fleets, staff plans to propose that "small" fleets be defined as those that could not support a natural gas refueling station. In general, the ARB believes this level is somewhere between 20- and 40-bus fleets. Staff is proposing that all small fleets would automatically qualify for the "incentive" path.

Describe the near-zero bus standard proposal.

To meet air quality goals, the ARB needs to pursue zero or near-zero technologies where it is feasible and cost-effective. Urban buses are such a category. As discussed earlier, several promising technologies are possible, independently or in tandem. Staff is proposing standards of 0.1 g/bhp-hr NOx and 0.00 g/bhp-hr PM. Those operators on the "conventional/advanced technology" path would be required to buy or lease buses with engines meeting these standards in the 2008 model-year. Those on the "incentive" path would be required to meet these standards in the 2012 model-year.

What is the ARB considering for school buses?
It is important to reduce emissions from school buses. A school bus travels far fewer miles than a transit bus – generally 15,000 miles annually, compared to over 40,000 miles; however, there are almost three times as many school buses, and many are very old, high-polluting diesel buses. Their emissions' impact on ozone formation may be small as fleets operate primarily outside the ozone season. However, reducing the direct exposure of students to toxic diesel particulates is a high priority for ARB.

Those school transportation operators with CNG buses are generally very enthusiastic about their new buses. Some have their own refueling stations; some share refueling stations with other local fleets. However, staff has found there are barriers to including school districts in the fleet rule. First, there are many small fleets; a joint-use refueling station will not always be available; and it would not be cost-effective to require small fleets to install this infrastructure. Second, there is a shortage of grant funds to subsidize the low-emission alternative-fuel buses and infrastructure. As few school districts charge students any fees to ride buses, transportation services must compete with all other school district operations for funding.

Therefore, the ARB is not including school districts in this fleet rule. Staff will evaluate a proposal in 2000 addressing school buses. In the interim, ARB staff will encourage transportation agencies to spend some of their air quality funds on school bus projects and air districts to subsidize school buses and infrastructure. Staff is also working with the California Energy Commission to secure additional school bus and infrastructure funding and investigating possible new sources of funds. As well, staff plans to work with local air districts and school districts to identify other voluntary and regulatory methods to reduce student exposure to toxic diesel particulates emitted by school buses.

Although the ARB is not proposing to include school buses in this proposal, some emission reductions are expected. First, the late-2002 heavy-duty engine requirements (2.4-2.5 g/bhp-hr NOx+NMHC) will apply to most school bus engines. Also, truck engines used to power full-size school buses would have to comply with new heavy-duty truck engine standards expected in the future. Finally, as discussed previously, the ARB is in the risk management phase for control of particulates from diesel-fueled engines. This work will be completed in early 2000. At that time, the ARB will evaluate whether any toxic-specific control measures are appropriate for school buses.

Are any alternatives being considered for the transit rule?
The staff has considered several different alternatives in the development of the current proposal. The original proposal was a straightforward requirement that would have required all transit operators to purchase only buses that meet lower-emission standards immediately. A second alternative that was analyzed was one in which a declining fleet average standard would be required. A fleet rule

provision that would update older technology is being evaluated. Finally, the staff is still considering including an alternative that would provide regulatory incentives for transit operators that move to near-zero technology quickly. Each of these options is presented below along with a discussion, and staff welcomes comments on each of these possibilities.

Low-Emission Standard: As discussed earlier, the staff originally considered a proposal that would set engine standards that would likely have required all new bus purchases to be cleaner alternative-fuel buses; they meet low emission NOx and PM levels now. In addition, the technology to achieve these benefits is already well established and many transit operators are converting their fleets to alternative fuels. Such a proposal would have provided significant emissions benefits.

As well, in September 1998, the ARB Board adopted Resolution 98-49, that urged State, local and federal agencies to join together with ARB in actions to “clean the fleet”.
ARB is on record as encouraging the replacement of diesel-fueled school and transit buses with cleaner alternative-fuel buses, including provision of necessary infrastructure and technical training. Subsequent to the adoption of this Resolution, ARB staff has contacted funding agencies in attempts to secure funding for cleaner alternative-fuel buses and infrastructure, and conducted other outreach efforts.

However, in the many meetings that staff had with transit districts and transportation agencies, several of them were strongly in favor of additional flexibility. The greatest challenge was developing a proposal with more flexibility that isn’t a “give-away”, i.e., a proposal that maintains the same emissions benefits as one that sets low emission standards. One proposal seriously considered was a fleet average rule.

Fleet Average Rule: A fleet average rule would be one that would not just consider new bus purchases but would also consider those buses already in the fleet. Diesel buses have become modestly cleaner over the past several years. For example, whereas the current NOx standard has been 4.0 g/bhp-hr since 1996, the standard was 6.0 g/bhp-hr from 1988 through 1990 and 5.0 g/bhp-hr from 1991 through 1995. The useful life of an urban bus is considered to be 12 years (although many operators operate older buses). If a transit operator has an evenly distributed fleet it would have three years of buses (1988-1990) at the 6.0 g/bhp-hr level, five years of buses (1991-1995) at the 5.0 g/bhp-hr level, and four years of buses (1996-1999) at the 4.0 g/bhp-hr level. Their current fleet average emission level would be approximately 4.9 g/bhp-hr NOx.

Although an evenly distributed fleet no older than 12 years would have a fleet average of 4.9 g/bhp-hr NOx, many operators have older buses and their actual in-use fleet average would be higher. However, staff would not propose a starting fleet average higher than 4.9 g/bhp-hr NOx since that, in effect, would provide a reward for those transit operators that have not yet replaced their old, very high-emitting diesel buses. In fact, a lower starting fleet average would seem to be appropriate. Several proactive transit districts such as LACMTA, Sacramento Regional Transit, and Sunline Transit have been purchasing low-emission buses for many years and their fleet average would be considerably less, in the range of 4.0 g/bhp-hr NOx. Thus, a fleet average standard that began around 4.9 g/bhp-hr would be extremely lax and provide no benefit with these fleets.

The gaps between the different operators is so large that a practical fleet average system could not be established unless it started out low enough to challenge even the proactive transit operators. Staff has had difficulty determining how such a proposal could work, and finds that only if credits could be bought and sold, could such a system provide emission benefits. The price of those credits would be established by supply and demand. However, a starting point for those credits would be in the range of $12,000/ton that is often the limit for cost-effective mobile source projects.

Therefore, if a fleet average rule were pursued, it would be one that requires an operator to determine its fleet average emissions every year, or every other year, and compare that with a declining ARB fleet average standard. The starting point could be a current level of approximately 4.0 g/bhp-hr NOx, with the next specified fleet average standard in the range of 3 g/bhp-hr NOx in 2003 and declining in subsequent years. Operators that did not meet these standards would have to purchase credits each year until they had met the declining fleet average standard. Operators that did not purchase any buses meeting the low-emission “incentive” levels would likely need to buy credits from those that did so. Price of the credits could be substantial depending on how much the transit operator would be willing to do in terms of fleet turnover, retrofits and repowers.

Several issues were raised in the analysis of this concept. First, as discussed, establishing the appropriate fleet average standards is difficult given the large gap that currently exists between different fleets. A second issue is that local air quality districts may be relying on low-emission transit buses in their clean air plans. Having the ability to purchase credits from another transit agency (possibly outside their air district) may provide flexibility but does not provide needed air quality benefits. A final issue is that the system is quite complex. Transit operators would have to track emission levels or standards of all their buses; annual fleet average determinations would need to be computed and submitted to ARB; and an entire credit system would need to be developed.

Update Older Technology: ARB is considering including an engine repower, certified retrofit, or bus replacement provision in its fleet rule. It would be based on the normal bus life of 12 years. For instance, it could require that all engines certified to over the 6.0 g/bhp-hr NOx standard be retrofitted or repowered, or the buses replaced, by the end of 2000. Bus engines certified to the 6.0 g/bhp-hr standard would have to be retrofitted or repowered, or the buses replaced, by the end of 2002, and 5.0 g/bhp-hr engines by the end of 2008. This would be in addition to any retrofits required under the U.S. Environmental Protection Agency urban bus retrofit program for particulate matter.

Near-Zero Option: A final option that the ARB is considering is one that would provide flexibility to those operators that want to move directly to the zero/near-zero technologies. Some operators have expressed a strong interest in fuel cell technology and an option may be developed which encourages operators to expeditiously implement such technologies.

What are the next steps?

Staff will make a more detailed proposal available on our web site (www.arb.ca.gov) shortly. We will also include draft regulatory language. The proposal outlined here is a staff proposal. It will be refined through the workshop process and will be presented to the ARB governing board at a regulatory hearing currently scheduled for January 2000. Public participation throughout the process is encouraged.

FIGURE 1
NOx STANDARDS COMPARISON

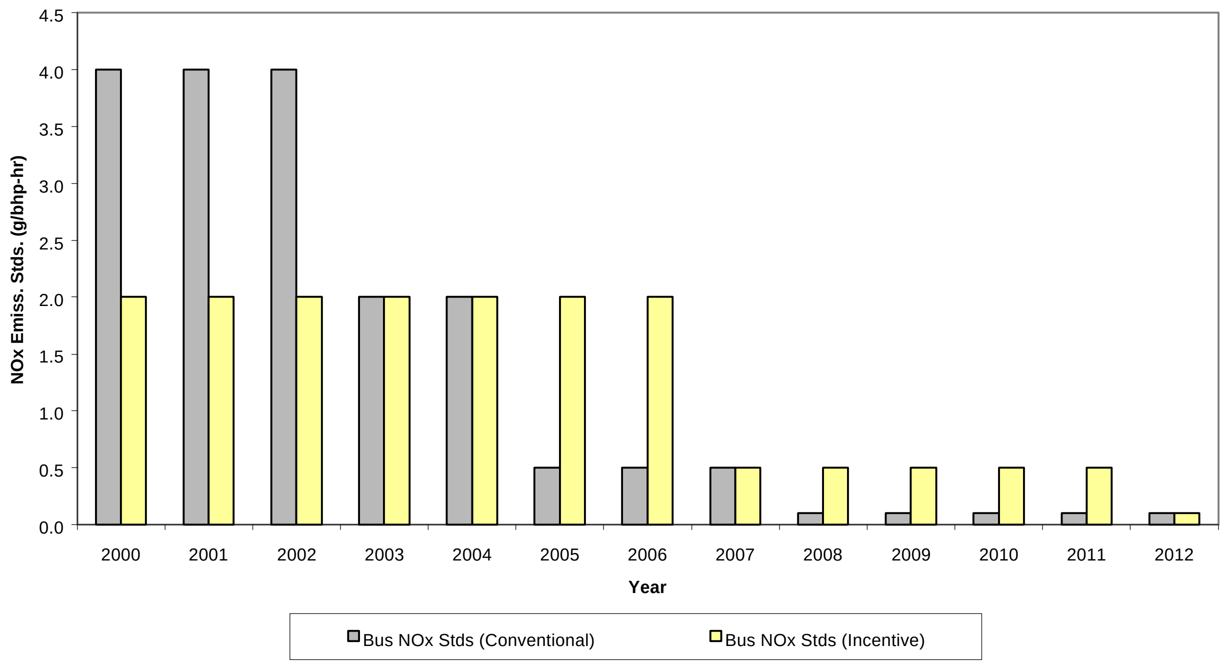
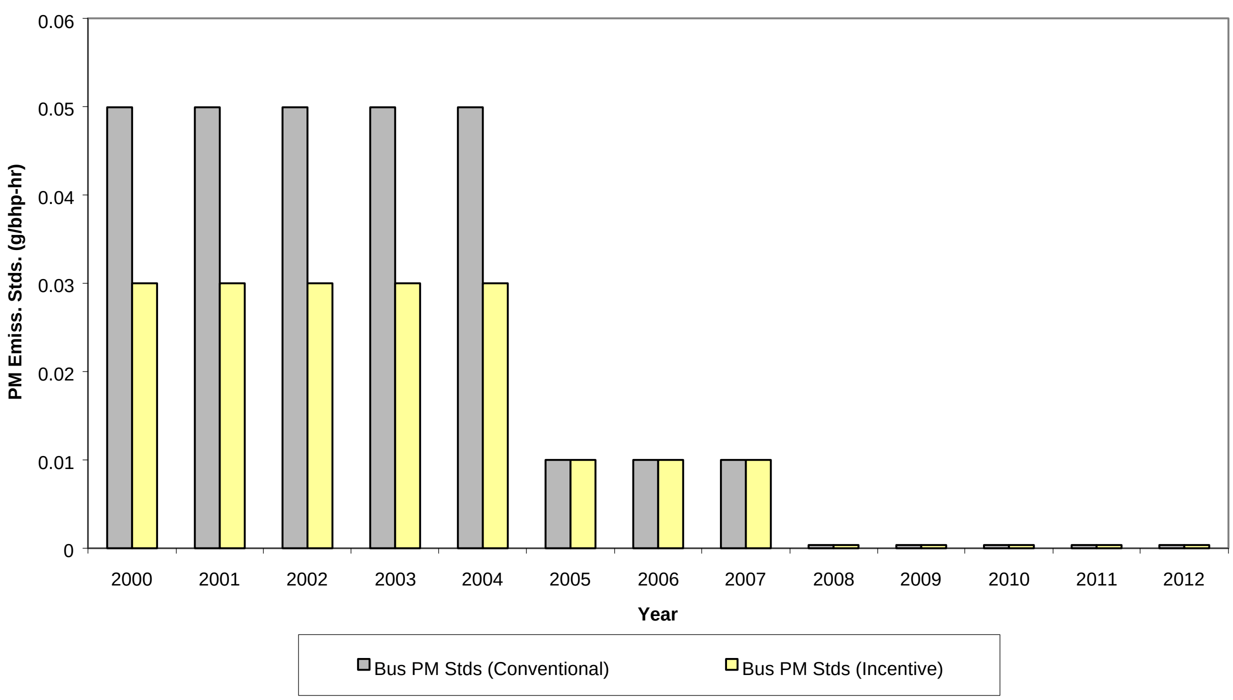


FIGURE 2
PM STANDARDS COMPARISON



Appendix I

Emission Control Technologies

Introduction
This section briefly discusses both commercially-available technology and emerging technology, that could be used in urban transit buses and school buses. Diesel engines have long been the engines of choice for use in urban transit buses. This is due to the efficiency and durability of diesel engines, as well as the operators' familiarity with diesel engine technology. Historically, this preference is also due to the lack of viable alternative engine technology for use in heavy-duty vehicle applications. This is no longer the case. Recent advances have enabled alternative engine technologies to close the performance and reliability gaps with diesel engines and, at the same time, clearly outperform diesel engines in terms of emissions. Some of these technologies are commercially available today, such as natural gas engines. Other technologies are being demonstrated that are expected to be available soon and have great potential to reduce emissions to near-zero or zero levels, such as hybrid-electric and fuel-cell technologies.

Diesel Technology
Diesel engines dominate the heavy-duty transportation sector due to their efficiency, long life, and fuel economy. Current emission control technologies such as combustion chamber modifications, advanced induction systems, and fuel injection strategies, such as retarded timing and high injection pressure, have resulted in diesel engines emitting about 30 percent less oxides of nitrogen (NOx) emissions than diesel engines manufactured a decade earlier. This achievement from diesel engines is significant but the level of NOx emissions from diesel engines is still about twice that of currently available alternative fuel engines. Regulatory pressure to produce even lower-emission diesel engines has increased efforts by engine manufacturers and aftermarket companies to develop advanced emission control technologies. To comply with future lower NOx emission standards, engine manufactures are researching several promising technologies such as cooled exhaust gas recirculation (EGR) and aftertreatment technology.

EGR is one of the most effective engine control methods for reducing NOx emissions. Spent combustion gases recirculated back into the intake system serve as a diluent to lower the oxygen concentration and to also increase the heat capacity of the air/fuel charge. Cooled EGR (cooled through the aftercooler) is used to minimize combustion temperatures. This reduces peak combustion temperature and the rate of combustion, thus reducing NOx emissions. However, particulate matter (PM) emissions may increase and fuel economy may decrease. The proper balance of EGR and temperature may provide the proper characteristics for decreasing NOx emissions while not increasing PM.

Currently, heavy-duty engine exhaust aftertreatment for NOx is limited by the lean environment, i.e., excess oxygen, of the diesel engines. Automotive catalysts rely on a nearly perfect balance of oxygen in the exhaust stream to maximize catalytic converter efficiency. One solution for heavy-duty vehicles is a selective catalytic reduction (SCR) system. These systems are common in stationary sources and are also used on some mobile sources in Europe. In this system, a reductant, commonly ammonia or urea, is injected into the exhaust upstream of the catalyst. In an SCR system with a reducing agent, the reductant decomposes and reacts across a catalyst to reduce NOx emissions. Cost is reasonable and NOx emission reductions are greater than 70 percent. Most of the issues appear to be pragmatic ones (packaging, communication of the SCR system with the engine's computer controls, etc.) These systems could be commercially available on new buses or even as retrofits within one to two years. For the longer term, NOx adsorbers could be available which would not require an additional reductant to be added. Again, cost would be reasonable. Efficiency could be greater than 70 percent and this technology could be available in the 2004 time frame. A critical element of many aftertreatment technologies is the necessity to have low-sulfur fuels. Although an SCR system may not necessarily need low-sulfur fuel, most other heavy-duty aftertreatment technologies could not function efficiently and reliably in an exhaust environment with significant quantity of sulfates present, due to trap plugging and catalyst fouling. Numerous programs are underway to evaluate appropriate levels of sulfur for future diesel fuel.

Current Natural Gas Technology

A number of alternative fuels are available for use in vehicular applications, such as methanol, ethanol, natural gas, propane, and others. Currently, however, only natural gas engine technologies have developed sufficiently for heavy-duty vehicle applications. This discussion, hence, only focuses on natural gas engine technology, for both compressed natural gas (CNG) and liquefied natural gas (LNG) engines.

Unlike diesel engines, which ignite by compression, natural gas engines are spark-ignited. In this respect, they are similar to gasoline engines, which also use the electrical energy provided by spark plugs to initiate the combustion process. Spark-ignition engines (SI engines) have slightly less efficiencies than compression-ignition (i.e., diesel, or CI, engines). Current technology for heavy-duty natural gas engines, such as lean-burn, closed-loop, and electronic fuel management system, has enabled natural gas engines to approach diesel-like fuel economy and performance, while emitting only one-half of the NOx and PM emissions compared to diesel engines. There is a slight increase in emissions of carbon monoxide, carbon dioxide and non-methane hydrocarbons from natural gas engines.

Both CNG and LNG heavy-duty engines operate in the same way; the difference in the two being the fuel storage and delivery methods, for both onboard the vehicle and at the fueling facility. CNG is natural gas under high pressure. To increase the energy content per unit of fuel storage volume, natural gas from pipeline is compressed to high pressure, usually around 3,600 to 4,000 pounds per square inch. The high pressure of CNG requires special tanks constructed from either steel or carbon composite. The weight and costs of CNG tanks are important factors to consider when specifying the number and types of tanks to be put on a bus. LNG is natural gas chilled to cryogenic temperature. At minus 260 degrees Fahrenheit (-260^{o}F) natural gas is condensed into a liquid. The advantage of LNG as a fuel is its greater energy density, compared to CNG, and its purity. Liquefaction removes most of the non-methane constituents present in natural gas, such as water, hydrogen sulfide, carbon dioxide, particulate and foreign matter, and the heavier hydrocarbons. The result is very pure natural gas that is 95 to 99 percent methane. Since LNG has higher energy density for a given storage volume than CNG, it could provide sufficient fuel for longer vehicle range and with less weight penalty than CNG. LNG is stored in double-walled vacuum-insulated tanks designed to minimize heat gain. The composition of LNG could be altered significantly, however, if LNG is left in storage for a long time and is exposed to high ambient temperatures, a process sometimes referred to as “LNG weathering”. Out of specification LNG could negatively affect engine performance.

Both CNG and LNG engines are currently available for heavy-duty vehicle applications. Urban transit buses have traditionally used CNG engines, although LNG transit buses have also been ordered. Some transit agencies, in fact, prefer LNG engines due to the increased range, along with reduced weight and costs, associated with LNG buses. Considerable emphasis is being placed on demonstrating efficient small-scale liquefaction units in California that could provide LNG fuel at a significantly reduced price. However, LNG is not readily available in California today, whereas the state’s utility companies could easily supply natural gas for compression for use in CNG buses. Most heavy-duty engine manufacturers have natural gas engines for sale. Some engine manufacturers have certified their natural gas engines to the ARB’s optional NOx standards that is approximately one-half of the existing NOx emission standard for heavy-duty engines.

The engine and aftertreatment technologies discussed in the Diesel Technology section are generally applicable to lean-burn natural gas engines as well. In some cases, higher aftertreatment efficiencies could be achieved. This is because the natural gas engine operates at a higher temperature and the higher temperatures can improve the efficiency of aftertreatment technologies. In addition, the natural gas does not contain sulfur so these systems would not have the efficiency and durability issues associated with sulfur poisoning from diesel fuel.

Emerging Engine Technology

Rapid advances in emission control technology are expected to substantially reduce both NOx and PM emissions from diesel and natural gas heavy-duty engines. In addition to diesel and natural gas engines, hybrid-electric and fuel-cell technology for transit bus application are developing rapidly and are expected to be commercially available in the next few years. These technologies have the potential to lower emissions from buses to zero or near-zero level. Hybrid-electric bus technology combines an internal combustion engine (diesel or a cleaner alternative fuel) and an electric motor to optimize the function of each to achieve very low emission levels and improved range. Hybrid-electric buses are currently under demonstration at several transit agencies. Fuel cell technology uses electrochemical reactions to provide power to operate the bus. The most promising fuel cell technology currently under demonstration is proton exchange membrane. In a fuel cell, hydrogen fuel dissociates in the presence of catalyst into free electrons and protons. The free electrons are conducted through an external circuit creating an electric current to power the fuel-cell engine. The protons migrate across the membrane, combine with oxygen in the air and electrons from the external circuit to form water and heat; no pollutants are created. The hydrogen use in fuel cells can come from any number of sources, including gasoline, methanol, and natural gas. Fuel-cell buses are also currently being demonstrated and tested at several transit agencies.

Appendix II

Costs Associated with Cleaner Alternative-Fuel Buses

How much do natural gas buses cost?
Natural gas buses are more expensive than diesel buses for two basic reasons. The most significant reason is that they are produced in smaller volume (and small volume almost always translates into higher cost). In addition, natural gas engines include a few additional components that the diesel engine does not have (e.g., spark plugs and coils). Although the incremental cost varies from one purchase to another, partly based on differences in specifications, it is generally in the range of $35,000 to $50,000 more for a full-size transit bus and $25,000 for a school bus. This is 12 to 16 percent more than the cost of a typical transit bus and approximately 25 percent more than the cost of a typical school bus.

How much of this cost a transit operator would have to secure from local transportation agencies and other local funding sources is not a straightforward issue. The Federal Transit Administration subsidizes up to 83 percent of the cost of a new alternative-fuel transit bus. In addition, local air district funding is available to many transit agencies that buy clean-fuel buses. In many cases, transit agencies have purchased low-emission natural gas buses at no additional cost to them because of the grant funds available.

School districts, however, are required to bear much of the additional costs. There are few dedicated State or local funds set aside to meet school transportation needs. Air quality funds are not so easily accessed, as school buses may not accumulate enough miles each year to meet the cost-effectiveness criterion of the air districts or the State. As well, school districts often need more than the incremental purchase cost to be able to buy any new buses at all.

Are there other capital costs associated with natural gas buses?
Yes. Refueling and facility costs are significant. For compressed natural gas (CNG), new pumps are needed and compressors are required. Compressing the gas allows more fuel to be stored on the bus as well as allowing faster filling of the on-board tanks. Fuel for LNG buses can be trucked to the site, or liquefied on site, come from a joint-use facility, or other otherwise provided.

Facility costs will vary based on the pressure of the available natural gas, space available for expansion, type of liquefaction and compression equipment, and the condition of the current facility. In the maintenance facility, methane monitoring devices, ventilation equipment, and non-explosive lighting fixtures are usually needed. Some small operators start their fleet conversions using less expensive slow-fill equipment and plan to install permanent fast-fill refueling capability when required. School buses may be fueled off-site at public or private fueling stations.

Total costs for a complete 200-bus facility changeover to CNG are in the range of three to four million dollars in California. Usually, there are not enough local air district or State incentive funds available to cover a significant portion of these costs. Federal funds could be available, or diverted from other sources, by the local transportation agencies that distribute federal funds by region.

Some transit agencies and school districts have begun contracting for on-site fueling services with natural gas facility providers. The companies build facilities and maintain them for a monthly fee that is added to the delivered cost of the fuel. In some cases, at the end of a contract with the provider, the bus operator owns the fueling station. Some transit operators prefer not to share management of their operations with others, but such arrangements have the potential to allow the operator to move to natural gas-fueled fleets with much lower up-front costs. As well, some operators sell CNG to other users to help pay for their refueling facilities.

The joint use of a refueling facility by several public and private fleets -- transit and school bus operators, post office fleets, paratransit and shuttle operators, and trucking fleets and so forth -- can reduce costs.

What about operating costs associated with natural gas buses?
Fuel price, fuel compression or liquefaction, facility maintenance, bus maintenance and other costs are defined as operating costs by major operators, though accounting procedures vary. ARB staff has found that different transit agencies report significantly different operating costs, based partly on size and location of their operations. Of major importance seems to be the training of the technical staff and mechanics to maintain more sophisticated computer-controlled engines. This is an issue not only with natural gas engines, but also with all future diesel engines. The majority of natural gas and diesel bus equipment is the same (frame, doors, seats, wheels, brakes, transmission, equipment for the disabled, etc.) so those maintenance costs should be relatively similar.

However, natural gas engines have some parts that are not on diesel engines and these parts can be relatively expensive due to their low sales volume. CNG buses are heavy due to the extra weight of the CNG tanks; LNG buses are not as heavy. One would expect to have incrementally greater brake wear on CNG buses than diesel buses. However, not all natural gas bus operators have observed this and it may only be an issue where buses are overloaded. Some maintenance costs can be lower. Natural gas engines also burn cleaner and therefore should have longer intervals between rebuilds.

New high-maintenance components may be needed in all diesel engines designed to comply with the 2002 oxides of nitrogen (NOx) requirements and the proposed 2005 NOx and particulate matter (PM) standards. Probably new fuel management systems, and aftertreatment devices such as particulate traps and catalysts, will be required that will increase the maintenance costs of diesel engines. These increases may tend to close any gap between the maintenance costs of diesel engines and alternative-fuel engines. Natural gas engines already meet the 2002 NOx requirement so will not have to undergo extensive redesign and improvements by manufacturers.

Some natural gas bus operators have converted their fleets to natural gas to save fuel costs. Natural gas prices are usually more stable than diesel fuel prices. In determining fuel costs per mile for CNG, both delivered price of the fuel and compression costs have to be considered. For LNG, fuel and liquefaction costs have to be considered. Until recently, diesel fuel prices have been very low so costs per mile have been very similar for CNG and diesel buses. Currently there is a saving in fuel costs per mile for CNG buses as diesel fuel is priced at about $1.40 per gallon and CNG at about $1.20 per diesel gallon equivalent. ARB staff estimates the low-sulfur diesel fuel that lower-emission diesel engines will require in the future will have an increased wholesale price of as much as 10 percent.

Several transit operators have tried to do an “apples-to-apples” comparison of CNG and diesel engine maintenance and repair costs. Invariably, these comparisons suffer from the same issue: CNG buses have not been on the road long enough to provide a true comparison. As expected, when CNG buses were first introduced in substantial quantities four years ago, there were problems. Since then, operators have been subjected to a fairly steep learning curve. Significant improvements have occurred, and many early problems have been solved. On the other hand, these early buses were under warranty, and although operators had to deal with increased down time, they were not responsible for many of the high repair costs. Transit operators are only now operating a significant number of CNG buses that are out of warranty. School bus operators report that maintenance requirements are less than diesel buses. Finally, CNG buses are only now reaching the point where normal engine overhauls are needed. It is not clear how far CNG buses can go before an overhaul – therefore the size of this benefit is not known. Generally, incentive funding is not available to subsidize any increased operating costs.

Although no comprehensive comparison of natural gas to diesel buses is possible at this time, ARB has analyzed operating costs reported by numerous transit agencies. We have reached these conclusions:

- Initially, there are higher maintenance costs for natural gas fleets. Availability of more reliable natural gas engines, and operation of diesel engines meeting future lower emission standards will tend to decrease this difference. Together, these changes should almost close the gap, and result in only slightly higher maintenance costs for natural gas engines.

- Fuel costs per mile, including natural gas compression or liquefaction, is less for natural gas fleets. The increased price of low-sulfur fuel needed for diesel engines in the future should make this difference in cost even greater.
- As a result, operating costs of new natural gas fleets in the future are estimated to be only slightly higher than that for new diesel fleets.
- The capital costs for natural gas fleets -- initial bus purchase price and the refueling and facility modification costs -- will continue to be higher than that for diesel fleets.

ARB staff has been charged with analyzing the funding available for increased capital costs. In general, funding -- from transportation, air quality, and energy sources -- is available to subsidize the incremental purchase price of natural gas buses, based on a normal turnover rate. However, so far the staff has not identified enough transportation or incentive funding to cover the entire cost of the infrastructure required to operate natural gas buses.